

AD-A140 762

LONG CYCLE LIFE SECONDARY LITHIUM CELLS UTILIZING
TETRAHYDROFURAN(U) EIC LABS INC NORWOOD MA
K M ABRAHAM ET AL. APR 84 TR-12 N00014-77-C-0155

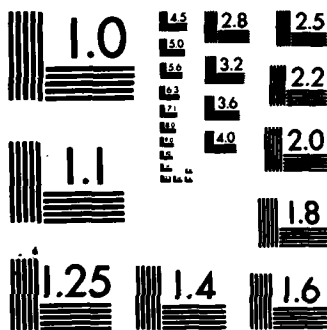
1/1

UNCLASSIFIED

F/G 10/3

NL

END



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

AD-A140 762

OFFICE OF NAVAL RESEARCH

Contract No. N00014-77-C-0155

TECHNICAL REPORT NO. 12

LONG CYCLE LIFE SECONDARY LITHIUM CELLS UTILIZING
TETRAHYDROFURAN

By

K. M. Abraham
J. S. Foos
J. L. Goldman

EIC Laboratories, Inc.
111 Downey Street
Norwood, Massachusetts 02062

Prepared for Publication in the
Journal of the Electrochemical Society

February 1984

Reproduction in whole or in part is permitted for any purpose
of the United States Government

Approved for Public Release, Distribution Unlimited.

DTIC
ELECTE
S MAY 04 1984
E

DTIC FILE COPY

84 05 03 007

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report No. 12	2. GOVT ACCESSION NO. ADA140762	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LONG CYCLE LIFE SECONDARY LITHIUM CELLS UTILIZING TETRAHYDROFURAN		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER C-480
7. AUTHOR(s) K. M. Abraham, J. S. Foos and J. L. Goldman		8. CONTRACT OR GRANT NUMBER(s) N00014-77-C-0155
9. PERFORMING ORGANIZATION NAME AND ADDRESS EIC Laboratories, Inc. 111 Downey Street Norwood, Massachusetts 02062		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research/ Chemistry Program Arlington, Virginia 22217		12. REPORT DATE April 1984
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Secondary lithium battery, non-aqueous electrolytes, tetrahydrofuran (THF), 2,methyl-tetrahydrofuran (2Me-THF), additives, 2,methyl-furan (2Me-F). Approx.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Cycle lives of secondary Li cells utilizing THF/LiAsF ₆ solutions have been significantly improved by the use of small amounts of additives such as 2,methyl-furan, 2,methyl-thiophene or similar unsaturated organic compounds. A most important consequence of the discovery has turned out to be the practical utility of the mixed electrolyte, 50 v/o THF:50 v/o 2Me-THF/LiAsF ₆ (1.5M). This solution combined with ~3.5 v/o 2Me-furan has enabled 5 A-hr Li/TiS ₂ cells to exhibit more than 200 cycles at 60% depth-		

DD FORM 1473

JAN 73

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

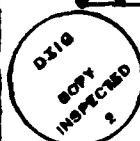
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

CONFIDENTIAL
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

of-discharge. This cycle life is twice that achieved with 2Me-THF/LiAsF₆(1.5M). In addition, the mixed electrolyte cells have shown low temperature discharge capabilities superior to those containing either THF/LiAsF₆(1.5M) or 2Me-THF/LiAsF₆(1.5M).

Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



ii
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LONG CYCLE LIFE SECONDARY LITHIUM CELLS
UTILIZING TETRAHYDROFURAN

K. M. Abraham*, J. S. Foos* and J. L. Goldman*
EIC Laboratories, Inc., 111 Downey Street, Norwood, MA 02062

The tetrahydrofuran(THF)/LiAsF₆ electrolyte solution, except for its high reactivity with Li (1), is highly desirable for use in ambient temperature rechargeable Li cells (2). In a recent patent application (3), we have disclosed that the use of unsaturated organic additives such as 2-methyl-furan (2Me-F) enables high efficiency Li cycling in THF/LiAsF₆. A most important consequence of this discovery has turned out to be the utility of the high rate, low temperature mixed solution, 50:50 THF:2Me-THF/LiAsF₆(1.5M) (2,4,5), in 5 A-hr Li/TiS₂ cells to achieve, for the first time, more than 200 cycles of 60% depth-of-discharge (d.o.d). The Li anode cycling efficiency in these 5 A-hr cells exceeded 97%. We now believe that this mixed electrolyte is significantly better than 2Me-THF/LiAsF₆ for use in ambient temperature secondary Li cells. The relevant data are reported in this communication.

In prior publications (6-8), we have reported on the superior ability of the 2Me-THF/LiAsF₆ solution to cycle Li with high efficiencies which span the range of 96-97.5% (Figure of Merit, F.O.M._{Li} = 25-40) for Li charge densities of 7-10 mA-hr/cm². A persistent impurity in distilled 2Me-THF is 0.2-0.4 volume-percent (v/o) of 2Me-F (4,7,9), the unsaturated analog of 2Me-THF (see Table 2 for structural formulas). In fact, most of the published

*Electrochemical Society Active Member
Key words: Li Battery, Electrolytes.

results discussing the use of 2Me-THF/LiAsF₆ in rechargeable Li cells have dealt with an electrolyte solution containing ~0.2-0.4 v/o 2Me-F. This has come about because of the difficulty of removing the 2Me-F by fractional distillation of the solvent.

Recently we have found that this 2Me-F can be completely converted into 2Me-THF by hydrogenating the "impure solvent" over a Pt catalyst at ambient temperature and pressure (3). Li/TiS₂ laboratory cells using the 2Me-F-free-2Me-THF/LiAsF₆ solution, to our surprise, have exhibited inferior cycle lives; typically, about half of that of cells utilizing the "regular electrolyte" with 0.2-0.4% 2Me-F. The cycle tests at 1 mA/cm² and 7 mA-hr/cm² were performed in 0.68 A-hr Li/TiS₂ laboratory test cells, identical to those we have previously described in ref. 7. Indeed, the cycle numbers for the various cells reported in Table 1 are directly comparable to those presented in Figures 4 and 5 of ref. 7. It should be noted that all cell capacities mentioned in this paper are based on 1e⁻/TiS₂. As discussed in ref. 7, the theoretical Li capacity in a cell is much larger than the TiS₂ capacity. Following the surprise with the 2Me-F-free-electrolyte, we deliberately prepared 2Me-F-containing solutions by adding 0.3, 0.6 or 1.2 v/o of 2Me-F into the solution in neat 2Me-THF, obtained via the hydrogenation procedure. Performance of laboratory Li/TiS₂ cells employing these solutions is summarized in Table 1. It is clear that 0.3 to 0.6 v/o of 2Me-F doubles the cycle life of 2Me-THF/LiAsF₆-based cells.

An obvious question is whether 2Me-THF/LiAsF₆ is less reactive in secondary Li cells than THF/LiAsF₆, as previously claimed (8). The answer

is yes, although about half of the cycles of the cell presented in Figure 5 of ref. 7 appears to be due to the effect of 2Me-F.

We have also found 2Me-F to improve substantially the cycle life of cells utilizing THF/LiAsF₆. Some relevant data are given in Table 1. Cells utilizing THF/LiAsF₆ plus 0.5 v/o 2Me-F exhibit about 100 cycles as opposed to 7 in 2Me-F-free cells. Interestingly enough, a significant increase in cycles is not seen at the higher 2Me-F concentrations of 1, 1.5 and 2 v/o. It appears from the data obtained from both THF and 2Me-THF cells, that there is a stoichiometric relationship between the amount of effective 2Me-F and the Li being electrochemically cycled. Our present data indicate that about 0.4 mmoles of 2Me-F is required per 1 A-hr of Li for the manifestation of an optimum additive effect in THF/LiAsF₆. This Li-to-additive mole ratio has been satisfactorily tested in 5 A-hr prismatic Li/TiS₂ cells (vide-infra). The practical significance of this discovery is very clear. For the first time, high rate, low temperature discharge and long cycle life have all been achieved in the same electrolytes, namely THF/LiAsF₆ and its blends.

We believe that 2Me-F is effective as a cycle life enhancing additive because it forms a protective film on the Li surface. The film may be of the solid electrolyte (10) or of the polymer electrolyte (11) type, enabling Li discharge and charge, while preventing or significantly slowing down direct chemical reactions at the Li surface. Further studies to fully elucidate the chemistry of the additive effect are in progress.

In laboratory test cells, the 50:50 THF:2Me-THF/LiAsF₆(1.5M) electrolyte solution with 0.5 v/o 2Me-F has given cycle lifes mid-way between

those given by cells containing the parent solutions plus the additive (see Table 1). However, in 5 A-hr prismatic Li/TiS₂ cells this order of additive effects changes. In these larger cells, employing a practical Li-to-electrolyte ratio, the mixed THF:2Me-THF solution plus 2Me-F has produced the longest cycle life. Thus a 5 A-hr Li/TiS₂ cell (12) utilizing a solution of the composition, THF (48.3 v/o):2Me-THF(48.3 v/o):2Me-F(3.4 v/o)/LiAsF₆ (1.5M), has given more than 225 cycles when cycled at a d.o.d. of 60% (Figure 1). As indicated earlier, the amount of the additive required is determined by the total Li in the cell, and the larger additive concentration in these cells is due to the larger Li to electrolyte ratio. Under similar cycling regimes, 2Me-THF/LiAsF₆ cells gave 125 cycles and the THF/LiAsF₆ cells 120 cycles. In all cases, cell failure occurred due to increased impedance and dendrite shorting. The blended solution, in addition, has exhibited relatively good thermal stability (see Table 1) and its low temperature performance is superior to that of the parent solutions. A 5 A-hr Li/TiS₂ cell employing the blended solution has yielded ~2.5 Ahr at -20°C at 2mA/cm² (2,4,5). For the same temperature and current density, capacities were non-existent in the cells utilizing the parent solutions. The superior -20°C performance of the mixed solution over THF/LiAsF₆, despite the higher conductivity of the latter (2), may be related to the more desirable Li⁺-solvates in the blend, permitting better Li⁺ diffusivities and a consequently high rate capability. The 2Me-THF system is impractical below 0°C because of the formation of sparingly soluble Li⁺-solvates (2,7).

In exploring the field, we have discovered other additives as well suitable for improving the cycle life of THF/LiAsF₆-based secondary Li cells. Some examples are given in Table 2. To date 2Me-F appears to be the most effective. Detailed studies of the various additives are in progress.

Acknowledgement

This work was supported by the Office of Naval Research. We appreciate discussions with Dr. S. B. Brummer.

REFERENCES

1. V. R. Koch, J. Electrochem. Soc., 126, 181 (1979).
2. K. M. Abraham and J. L. Goldman, J. Power Sources, 9, 239 (1983).
3. K. M. Abraham, S. B. Brummer and J. S. Foos, U. S. Patent filed (1983).
4. K. M. Abraham, P. B. Harris and D. L. Natwig, J. Electrochem. Soc., 130, 2309 (1983).
5. K. M. Abraham, "Ambient Temperature Secondary Lithium Cells", in Lithium Chemistry, R. O. Bach ed., John Wiley and Sons (book to be published).
6. K. M. Abraham, J. L. Goldman and M. D. Dempsey, J. Electrochem. Soc., 128, 2493 (1981).
7. K. M. Abraham, J. L. Goldman and D. L. Natwig, J. Electrochem. Soc., 129, 2404 (1982).
8. J. L. Goldman, R. M. Mank, J. H. Young and V. R. Koch, J. Electrochem. Soc., 127, 1461 (1980).
9. S. P. S. Yen, D. Shen, R. P. Vasquez, F. J. Grunthaner and R. B. Somoano, J. Electrochem. Soc., 128, 1434 (1981).
10. E. Peled, J. Electrochem. Soc., 126, 2047 (1979).
11. M. Garreau, Fall Meeting of the Electrochemical Society, Washington, D. C. (1983). Abstract No. 58.
12. K. M. Abraham, J. L. Goldman, P. B. Harris, J. Avery and S. B. Brummer, Fall Meeting of the Electrochemical Society, Detroit, MI (1982), Extended Abstract No. 314.

FIGURE CAPTION

Figure 1. Typical cycles of a 5 A-hr theoretical capacity Li/TiS₂ cell utilizing THF(48.3 v/o):2Me-THF(48.3 v/o):2Me-F(3.4 v/o)/LiAsF₆(1.5M). Current: Cycles 1 and 100, id = 0.5A, ic = 0.25A; Cycles 160 and 203, id = ic = 0.25A. All cycling was performed to a depth-of-discharge of 60% (3A-hr).

TABLE CAPTIONS

Table 1 Effect of 2-Methyl-furan (2Me-F) on the Cycle Life of Li/TiS₂ Laboratory Cells^(a)

Table 2 Effect of Several Additives^(a) on the Cycle Life of Li/TiS₂ Laboratory Cells Utilizing THF/LiAsF₆(1.5M)

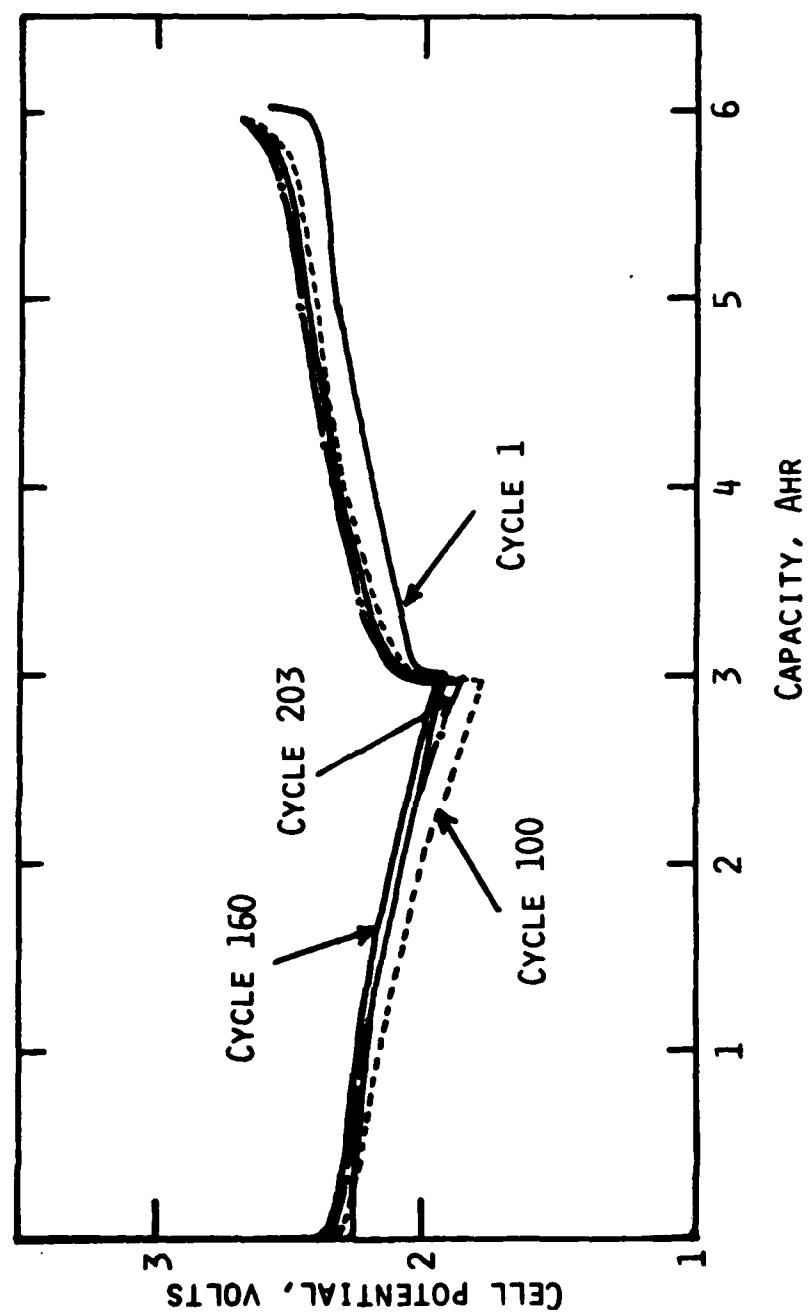


FIG. 1

Cell No.	Electrolyte	Amount of 2Me-F v/o	Number of Cycles ^(b)
98-18	2Me-THF ^(c) / LiAsF ₆ (1.4M) ↓	0.0	96
98-07		0.3	150
98-26		0.6	177
98-29		1.2	198
140-19	THF / LiAsF ₆ (1.5M) ↓	0.0	7
35-10		0.5	111
35-32 ^(d)		0.5	92
98-06		1.0	96
98-11		1.5	110
98-15		2.0	105
101	2Me-THF (50 v/o): THF (50 v/o) / LiAsF ₆ (1.5M)	0.5 ^(e)	145
102	2Me-THF (50 v/o): THF (50 v/o) / LiAsF ₆ (1.5M)	1.0	140

(a) Each type of cell has been cycled at least in duplicate. Temperature, 25°C.


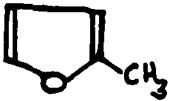




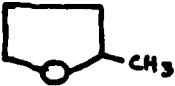
(b) Obtained at 1 mA/cm² for 7 mA-hr/cm²; compare Fig. 5 in Ref. 7.

(c) Obtained by hydrogenating distilled 2Me-THF containing 0.2-0.4 v/o 2Me-F over Pt catalyst and subsequently preparing the LiAsF₆ solution.

(d) Stored 14 days at 50°C prior to cycling.

(e) Stored for 1 month at 50°C prior to cycling. Unstored cells gave ~10 cycles less.

Table 1

<u>Additive(c)</u>		<u>Percent by Volume (v/o)</u>	<u>Number of Cycles(b)</u>
None	-	-	7
Furan,		0.5	46
2-Methyl-furan,		0.5	110
2,5-dimethyl-furan,		0.5	37
2,5-dimethyl-thiophene,		0.5	38
4,5-dihydropyran,		0.5	32
3,4-dihydrofuran,		0.5	28
2-methyl-THF,		0.5	8

(a) Additional additives are given in our patent (3).

(b) Obtained at 7 mA-hr/cm² and 1 mA/cm² (7).

(c) It appears that at least one double bond in the ring is necessary.

Table 2

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	<u>No. Copies</u>		<u>No. Copies</u>
Office of Naval Research Attn: Code 413 800 N. Quincy Street Arlington, Virginia 22217	2	Naval Ocean Systems Center Attn: Technical Library San Diego, California 92152	1
ONR Pasadena Detachment Attn: Dr. R. J. Marcus 1030 East Green Street Pasadena, California 91106	1	Naval Weapons Center Attn: Dr. A. B. Amster Chemistry Division China Lake, California 93555	1
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360	1	Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko Port Hueneme, California 93401	1	Dean William Tolles Naval Postgraduate School Monterey, California 93940	1
Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375	1	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12	Mr. Vincent Schaper DTNSRDC Code 2830 Annapolis, Maryland 21402	1
DTNSRDC Attn: Dr. G. Bosmajian Applied Chemistry Division Annapolis, Maryland 21401	1	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1	Mr. A. M. Anzalone Administrative Librarian PLASTEC/ARRADCOM Bldg 3401 Dover, New Jersey 07801	1

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. Paul Delahay
Department of Chemistry
New York University
New York, New York 10003

Dr. P. J. Hendra
Department of Chemistry
University of Southampton
Southampton SO9 5NH
United Kingdom

Dr. T. Katan
Lockheed Missiles and
Space Co., Inc.
P.O. Box 504
Sunnyvale, California 94088

Dr. D. N. Bennion
Department of Chemical Engineering
Brighma Young University
Provo, Utah 84602

Dr. R. A. Marcus
Department of Chemistry
California Institute of Technology
Pasadena, California 91125

Mr. Joseph McCartney
Code 7121
Naval Ocean Systems Center
San Diego, California 92152

Dr. J. J. Auburn
Bell Laboratories
Murray Hill, New Jersey 07974

Dr. Joseph Singer, Code 302-1
NASA-Lewis
21000 Brookpark Road
Cleveland, Ohio 44135

Dr. P. P. Schmidt
Department of Chemistry
Oakland University
Rochester, Michigan 48063

Dr. H. Richtol
Chemistry Department
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. E. Yeager
Department of Chemistry
Case Western Reserve University
Cleveland, Ohio 44106

Dr. C. E. Mueller
The Electrochemistry Branch
Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, Maryland 20910

Dr. Sam Perone
Chemistry & Materials
Science Department
Lawrence Livermore National Lab.
Livermore, California 94550

Dr. Royce W. Murray
Department of Chemistry
University of North Carolina
Chapel Hill, North Carolina 27514

Dr. G. Goodman
Johnson Controls
5757 North Green Bay Avenue
Milwaukee, Wisconsin 53201

Dr. B. Brummer
EIC Incorporated
111 Chapel Street
Newton, Massachusetts 02158

Dr. Adam Heller
Bell Laboratories
Murray Hill, New Jersey 07974

Electrochimica Corporation
Attn: Technical Library
2485 Charleston Road
Mountain View, California 94040

Library
Duracell, Inc.
Burlington, Massachusetts 01803

Dr. A. B. Ellis
Chemistry Department
University of Wisconsin
Madison, Wisconsin 53706

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. M. Wrighton
Chemistry Department
Massachusetts Institute
of Technology
Cambridge, Massachusetts 02139

Dr. B. Stanley Pons
Department of Chemistry
University of Utah
Salt Lake City, Utah 84112

Donald E. Mains
Naval Weapons Support Center
Electrochemical Power Sources Division
Crane, Indiana 47522

S. Ruby
DOE (STOR)
M.S. 6B025 Forrestal Bldg.
Washington, D.C. 20595

Dr. A. J. Bard
Department of Chemistry
University of Texas
Austin, Texas 78712

Dr. Janet Osteryoung
Department of Chemistry
State University of New York
Buffalo, New York 14214

Dr. Donald W. Ernst
Naval Surface Weapons Center
Code R-33
White Oak Laboratory
Silver Spring, Maryland 20910

Mr. James R. Moden
Naval Underwater Systems Center
Code 3632
Newport, Rhode Island 02840

Dr. Bernard Spielvogel
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

Dr. William Ayers
ECD Inc.
P.O. Box 5357
North Branch, New Jersey 08876

Dr. M. M. Nicholson
Electronics Research Center
Rockwell International
3370 Miraloma Avenue
Anaheim, California

Dr. Michael J. Weaver
Department of Chemistry
Purdue University
West Lafayette, Indiana 47907

Dr. R. David Rauh
EIC Corporation
111 Chapel Street
Newton, Massachusetts 02158

Dr. Aaron Wold
Department of Chemistry
Brown University
Providence, Rhode Island 02192

Dr. Martin Fleischmann
Department of Chemistry
University of Southampton
Southampton SO9 5NH ENGLAND

Dr. R. A. Osteryoung
Department of Chemistry
State University of New York
Buffalo, New York 14214

Dr. Denton Elliott
Air Force Office of Scientific
Research
Bolling AFB
Washington, D.C. 20332

Dr. R. Nowak
Naval Research Laboratory
Code 6130
Washington, D.C. 20375

Dr. D. F. Shriver
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Dr. Aaron Fletcher
Naval Weapons Center
Code 3852
China Lake, California 93555

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. David Aikens
Chemistry Department
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. A. P. B. Lever
Chemistry Department
York University
Downsview, Ontario M3J1P3

Dr. Stanislaw Szpak
Naval Ocean Systems Center
Code 6343, Bayside
San Diego, California 95152

Dr. Gregory Farrington
Department of Materials Science
and Engineering
University of Pennsylvania
Philadelphia, Pennsylvania 19104

M. L. Robertson
Manager, Electrochemical
and Power Sources Division
Naval Weapons Support Center
Crane, Indiana 47522

Dr. T. Marks
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Dr. Micha Tomkiewicz
Department of Physics
Brooklyn College
Brooklyn, New York 11210

Dr. Lesser Blum
Department of Physics
University of Puerto Rico
Rio Piedras, Puerto Rico 00931

Dr. Joseph Gordon, II
IBM Corporation
K33/281
5600 Cottle Road
San Jose, California 95193

Dr. D. H. Whitmore
Department of Materials Science
Northwestern University
Evanston, Illinois 60201

Dr. Alan Bewick
Department of Chemistry
The University of Southampton
Southampton, SO9 5NH ENGLAND

Dr. E. Anderson
NAVSEA-56Z33 NC #4
2541 Jefferson Davis Highway
Arlington, Virginia 20362

Dr. Bruce Dunn
Department of Engineering &
Applied Science
University of California
Los Angeles, California 90024

Dr. Elton Cairns
Energy & Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Dr. D. Cipris
Allied Corporation
P.O. Box 3000R
Morristown, New Jersey 07960

Dr. M. Philpott
IBM Corporation
5600 Cottle Road
San Jose, California 95193

Dr. Donald Sandstrom
Department of Physics
Washington State University
Pullman, Washington 99164

Dr. Carl Kannewurf
Department of Electrical Engineering
and Computer Science
Northwestern University
Evanston, Illinois 60201

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. Robert Somoano
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

Dr. Johann A. Joebstl
USA Mobility Equipment R&D Command
DRDME-EC
Fort Belvoir, Virginia 22060

Dr. Judith H. Ambrus
NASA Headquarters
M.S. RTS-6
Washington, D.C. 20546

Dr. Albert R. Landgrebe
U.S. Department of Energy
M.S. 68025 Forrestal Building
Washington, D.C. 20595

Dr. J. J. Brophy
Department of Physics
University of Utah
Salt Lake City, Utah 84112

Dr. Charles Martin
Department of Chemistry
Texas A&M University
College Station, Texas 77843

Dr. H. Tachikawa
Department of Chemistry
Jackson State University
Jackson, Mississippi 39217

Dr. Theodore Beck
Electrochemical Technology Corp.
3935 Leary Way N.W.
Seattle, Washington 98107

Dr. Farrell Lytle
Boeing Engineering and
Construction Engineers
P.O. Box 3707
Seattle, Washington 98124

Dr. Robert Gotscholl
U.S. Department of Energy
MS G-226
Washington, D.C. 20545

Dr. Edward Fletcher
Department of Mechanical Engineering
University of Minnesota
Minneapolis, Minnesota 55455

Dr. John Fontanella
Department of Physics
U.S. Naval Academy
Annapolis, Maryland 21402

Dr. Martha Greenblatt
Department of Chemistry
Rutgers University
New Brunswick, New Jersey 08903

Dr. John Wasson
Syntheco, Inc.
Rte 6 - Industrial Pike Road
Gastonia, North Carolina 28052

Dr. Walter Roth
Department of Physics
State University of New York
Albany, New York 12222

Dr. Anthony Sammells
Eltron Research Inc.
710 E. Ogden Avenue #108
Naperville, Illinois 60540

Dr. W. M. Risen
Department of Chemistry
Brown University
Providence, Rhode Island 02192

Dr. C. A. Angell
Department of Chemistry
Purdue University
West Lafayette, Indiana 47907

Dr. Thomas Davis
Polymer Science and Standards
Division
National Bureau of Standards
Washington, D.C. 20234

John F. Kincaid
Kaman Sciences Corporation
1911 Jefferson Davis Highway
Suite 1200
Arlington, VA 22202

END

FILMED

6-84

DTIC

FILMED

6-84

